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# HIGH ALTITUDE PLASMA EFFECTS

TRW Systems Group

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13. ABSTRACT


A major objective of this contract is to construct a Quiescent Uniform Ionospheric Plasma Simulator (QUIPS) to be used in analyzing and modeling the results of various field experiments in which a region of the ionosphere was artificially excited by a radar scattering. QUIPS will consist of a cylindrical vacuum chamber with interior dimensions 7' diameter x 12' long, whose interior is lined with approximately 10,000 permanent magnets (1"x1"x1") and 500 filaments in order to produce a plasma with a density of $10^{11}$ to $10^{12}$ electrons per $cm^3$. The laboratory experiments employing QUIPS, to be performed as follow-on activities, will involve millimeter wavelength microwave scattering from a region of the plasma which has been excited by 10 cm wavelength microwave.

In this report the general design considerations for the facility are reviewed and a final design and fabrication schedule is presented. The current status of the construction as well as some of the preparations for the performance of the follow-on activities are described.




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| PLASMA | | | | | | |
| IONOSPHERIC SIMULATOR | | | | | | |
| MICROWAVE SCATTERING | | | | | | |

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Interim Report

by

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This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by Vince Coyne under Contract No. F30602-72-C-0304.

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PUBLICATION REVIEW

This technical report has been reviewed and is approved.

Joseph J. Simons
For Vincent J. Coyne
RADC Project Engineer

RADC Contract Engineer

Summary

The purpose of this project is to construct a Quiescent Uniform Ionospheric Plasma Simulator (QUIPS) to be used in analyzing and modeling the results of various field experiments in which a region of the ionosphere was artificially excited by a ground based HF (4-12 MHz) transmitter and probed by higher frequency Thompson radar scattering. QUIPS will consist of a cylindrical vacuum chamber with interior dimensions 7' diameter x 12' long, whose interior is lined with approximately 10,000 permanent magnets (1"x1"x1") and 500 filaments in order to produce a plasma with a density of $10^{11}$ to $10^{12}$ electrons per $cm^3$. The laboratory experiments employing QUIPS, to be performed as follow-on activities, will involve millimeter wavelength microwave scattering from a region of the plasma which has been excited by 10 cm wavelength microwaves.

In this report the general design considerations for the facility are reviewed and a final design and fabrication schedule is presented. The current status of the construction as well as some of the preparations for the performance of the follow-on activities are described.

In this report we shall review the progress made, from 28 February 1972 to the present, on the design and fabrication of the large Quiescent Uniform Ionospheric Plasma Simulator (QUIPS) currently under construction at TRW. We shall outline the major physical considerations leading to the specific design adopted, and will present a schedule detailing our current predictions as to the time of delivery of required components, manufacture, and initial checkout.

## General Design Considerations

Since the primary use of the QUIPS device is for the performance of microwave scattering experiments, it must produce a large, quiescent plasma (fluctuation $\delta n/n \approx 10^{-3}$). Furthermore, in order to model the physical effects which occur in the ionosphere the plasma must be spatially highly uniform. These considerations initially led us to propose the construction of a scaled-up version of the magnetically-confined double plasma (DP) device invented by R. Limpacker, K.R. MacKenzie and R. Taylor (see Figure 1). As in the ionosphere, the plasma will be pumped above the threshold for parametric instabilities by irradiating it with a high-frequency (microwave in the case of the laboratory plasma) electromagnetic wave from an antenna. In order to avoid reflections from the walls and to produce a well defined pump field pattern, it is necessary that the diameter of the plasma (D) be much greater than the wavelength of the pump radiation ($\lambda_0$). Since the pump frequency matches the plasma frequency at some point in the plasma, $\lambda_0 \propto n_0^{-1/2}$ ($n_0$ is the plasma density). Hence, it is necessary to achieve the maximal $n_0$ to obtain the minimal $\lambda_0$. We are of the opinion that $n_0 \geq 10^{12} cm^{-3}$ is achievable, however, we have set a conservative design goal of $n_0 = 10^{11} cm^{-3}$. For that density, $\lambda_0 = 10$ cm.

For a given $\lambda_0$ and r, where r is the radius of the pump microwave dish, the radius of the radiation pattern a distance L from the dish is

$r + \lambda L/r \equiv R$. Thus the minimum value of $R = 2\sqrt{\lambda_o L}$, for $r = \sqrt{\lambda_o L}$. In order to produce a nearly plane wave pump excitation, we must satisfy $(r/\lambda_o) > 3$. We have chosen $r = 5\lambda_o = 50$ cm, whereupon from the above relations L must exceed 250 cm ($\approx$ 8 ft.), and the diameter of the tank must exceed 4r = 200 cm (6½ ft.). If a second plasma chamber is required for DP operation, the tank length should be at least 12 feet.

For a 7'x12' cylindrical plasma with $n_o \approx 10^{11}$, approximately 1000 filaments are required to generate the plasma and 10,000 permanent magnets are required to contain it. To preserve the field strength of the magnets, some facility must be provided to shield them from the filament heat. Several designs of the vacuum chamber, and magnet supporting and heat shielding framework, were considered before the design reported here was adopted.

## Final Design, and Fabrication Schedule

A 7'x12' vacuum chamber, which is available to us beginning about the middle of June, was located at the TRW facility and was reserved for our use (see Figs. 2 and 3). A modular supporting structure for the magnets and filaments is used which consists of 13 sets of rings, to be connected in series to form a 12' supporting shell. To reduce the stress on the supporting modular structures, lightweight ferrite magnets are used. To solve the heat removal problem, the magnets, enclosed in aluminum cans with one open end to be placed against the aluminum bars connecting the rings, are screwed onto the inner part of the rings. An axial view of the interior structure, showing the mounted magnet containers and filaments, is given in Fig. 4. In Fig. 5, a segment of three rings, viewed radially outward from a point on the axis of the rings, is shown. Aluminum bars, magnet containers and filaments may also be seen there. The rings are hollow and water-cooled. A cross-section of a three-ring segment,

showing the coolant (water), aluminum bars, filament holders and filaments, and a cross-section of magnet containers with magnets in place, is shown at the top of Fig. 5 and in Fig. 6. The construction and replacement of the filaments has been simplified by the adoption of a snap-on design.

A delivery schedule for the various components is shown in Table I. An itemization of the assembly tasks and tentative schedule of completion is given in Tables II and III. Assuming all components are delivered on schedule, we estimate the first turn-on period of the plasma to be 7 - 11 August 1972.

Our design goals for the completed device are as follows:

$$0 \lesssim n_o \lesssim 10^{12} cm^{-3},\ 1 \lesssim T_e \lesssim 4 \text{ ev.},\ 0.1 \lesssim T_i \lesssim 1 \text{ ev.},$$

$$\text{fluctuation } \left\langle \frac{\delta n}{n_o} \right\rangle \lesssim 10^{-3} .$$

In addition, by a judicious arrangement of the filaments along the axis, we anticipate that we can produce a uniform density gradient

$$L \cong \left(\frac{1}{n_o} \frac{\partial n}{\partial z}\right)^{-1} \gtrsim 10^3 cm.$$

Current Status

The items listed below have been partially completed as of this date.

1) The 7x12' vacuum tank is available for experiments.

2) A support frame for the magnet structure has been assembled (see Figures 7 and 8).

3) The filament holders are constructed.

4) The magnet cans are prepared (see Figure 9).

5) The support bars for the magnets have been cut, drilled and tapped (50% completed).

6) The wheel housing supporting the magnet cage are under construction.

7) The mounting of magnets on the support bars is in progress (see Figures 9 and 10).

8) The heli-arc welding of the rings for the magnet cage is in progress.

9) A test plasma facility has been constructed (see Figures 11 and 12).

10) The mechanical design for the probe drive system has been finished.

11) The electronic probe drive circuit system is under construction.

12) The regulated power supplies for the filaments and the discharge are made available.

13) Velocity analyzers and Langmuir probes and the accompanying electronic circuits are under construction.

14) The RF pump system is designed; a 300 Watt magnetron, the antenna and the lens are available. Microwave absorbers are tested for operation in high vacuum at high temperatures (see Figures 7 and 8).

15) The microwave scattering experiment has been designed and parts are being ordered.

## Test Plasma Facility

A small scale version of the large plasma device has been built, first, to test the basic plasma parameters, and second, to test components which will actually be used in the large plasma device. The test chamber uses the same magnets, magnet spacings, filaments and other components as are being used for the large plasma facility. It has been verified that the out-gassing of the permanent magnets does not present any problems. The basic plasma parameters being measured presently are the electron density, electron temperature, ion temperature, density fluctuations and density gradients as a function of discharge voltage and current, gas pressure and type of gas. Other basic properties of the discharge to be checked are filament lifetime, arcing, and out-gassing properties. The test facility is very useful in testing components being used in the large plasma device. Presently, Langmuir probes, ion velocity analyzers and RF probes for excitation and detection of plasma waves at 2.45 GHz are being tested. The high power microwave transmission lines for 2.45 GHz at 300 W are being tested for breakdown in vacuum. The different effects of internal vs external magnetic field coils can be easily studied with a small test chamber.

## Table I. Component Delivery Schedule

Key:
1 - Ordered
2 - In shop
3 - Delivered

| | May 15 | May 27 | June 5 | June 12 | June 19 | June 26 | July 3 | July 10 | July 17 |
|---|---|---|---|---|---|---|---|---|---|
| **Magnets** | | | | | | | | | |
| Ferrite magnets | | 3 | | | | | | | |
| Magnet covers | | | 3 | | | | | | |
| **Support for Magnets** | | | | | | | | | |
| Rings | | 1 | | | | | | | 2 |
| Bars for magnet mountings | 2 | | | | | | | | |
| Wheels housing | 2 | | | | | | | | |
| **Filaments** | | | | | | | | | |
| Wire | | | 3 | | | | | | |
| Insulator | | | 3 | | | | | | |
| Plugs | 3 | | | | | | | | |
| Copper rings for conductors | 3 | | | | | | | | |
| Ceramic beads | 1 | 3 | | | | | | | |
| Ceramic stand-off | 1 | 3 | | | | | | | |
| **Storage Frame** | | | | | | | | | |
| H-beam | 1 | 2 | | | 3 | | | | |
| I-beam | 1 | 2 | | | 3 | | | | |
| **Flanges** | | | | | | | | | |
| Vacuum chamber port covers | | | | | 1 | | | | |
| **Internal B Field** | | | | | | | | | |
| Coils | | | | | | 2 | | | |
| Power supplies | | | | | | | | | |

## Table II. Fabrication Tasks

1. Assembly of Magnet Cage on Support Frame*
   (Rings, Bars, End Plates, Rollers)

2. Connection of Cooling System

3. Mounting of Magnets

4. Construction of Filament Holders with Tungsten Wire

5. Installing of Filament Bus Bars, Isolation with
   Glass Tape and Mounting of Filament Holders

6. Assembly of Support Frame for Magnet Cage

7. Construction of Support for 1 Man to Enter Chamber
   without Touching Walls (for filament repair, probe
   installation, etc.).

8. Installation of Cage in Vacuum Chamber

9. Construction and Connection of Vacuum-tight Flanges
   with Feedthroughs for Cooling Water, Filament
   and Discharge Currents, Gas Inlet, Probes,
   Microwaves, etc.

10. Construction of Axial and Radial Probe Drive Systems
    a) Mechanical System
    b) Electronic System

11. Construction and Installation of Internal Helmholtz
    Coil

12. Outgassing Period and Connection of External Power,
    Water, Gas, Diagnostics

13. Construction of Electronic Circuits (Probe Sweepers,
    Arcing Protection, Diagnostics)

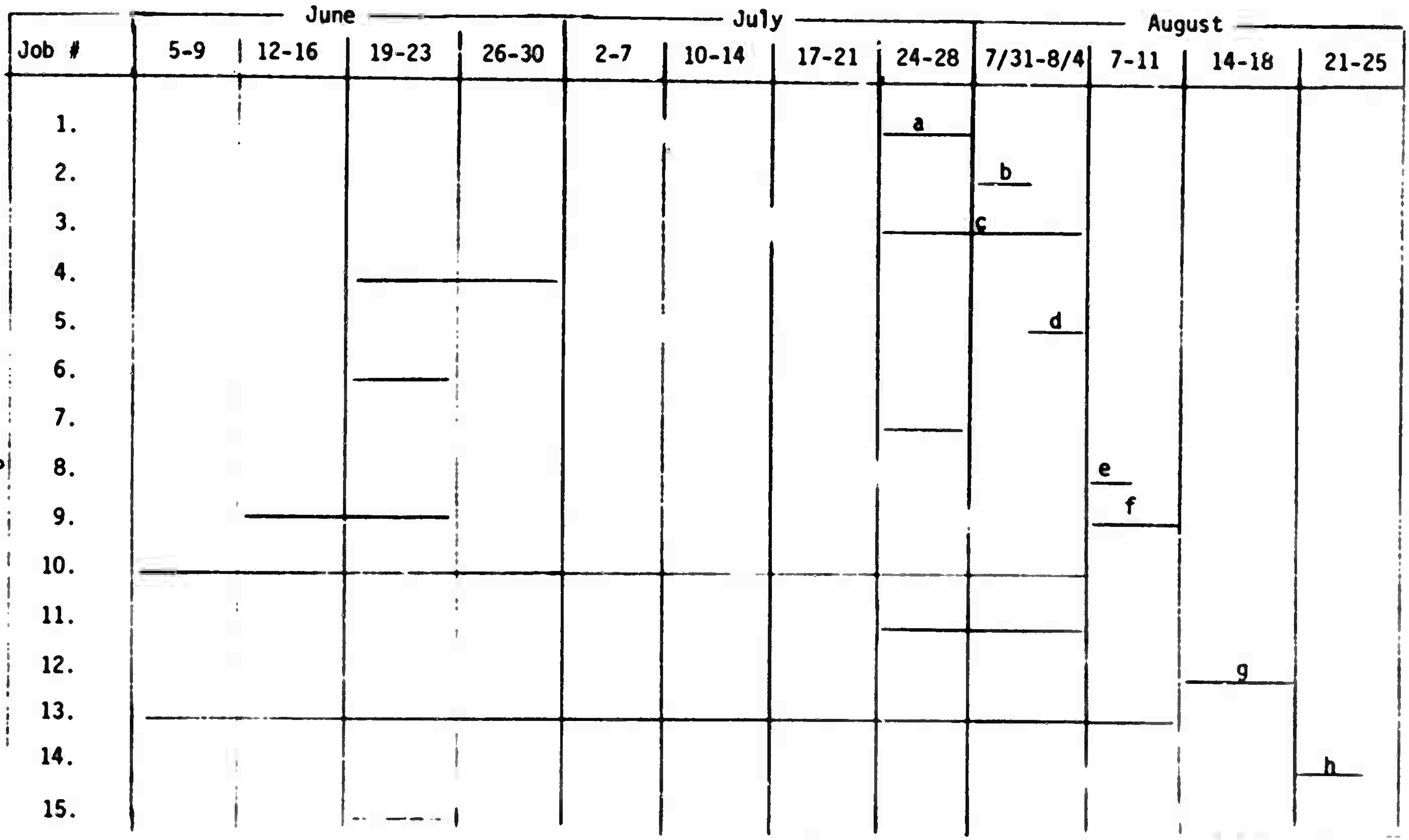
14. First Turn-on and Tests

15. Construction of Test Chamber

* Due to vacuum bar problems in the first fabrication of the rings by an outside vendor the rings had to be rewelded which delayed the assembly by two weeks.

Table III. Schedule of Task Completion

1 9 7 2




Critical sequence, a - h.

Figure 1. Double Plasma (DP) device of Limpacher and MacKenzie. The cylindrical magnet supporting frame 15" diameter x 20" length.

Figure 2. Vacuum chamber. Interior dimensions 7' diameter x 12' length.

Figure 3. Vacuum chamber. Interior dimensions 7' diameter x 12' length.

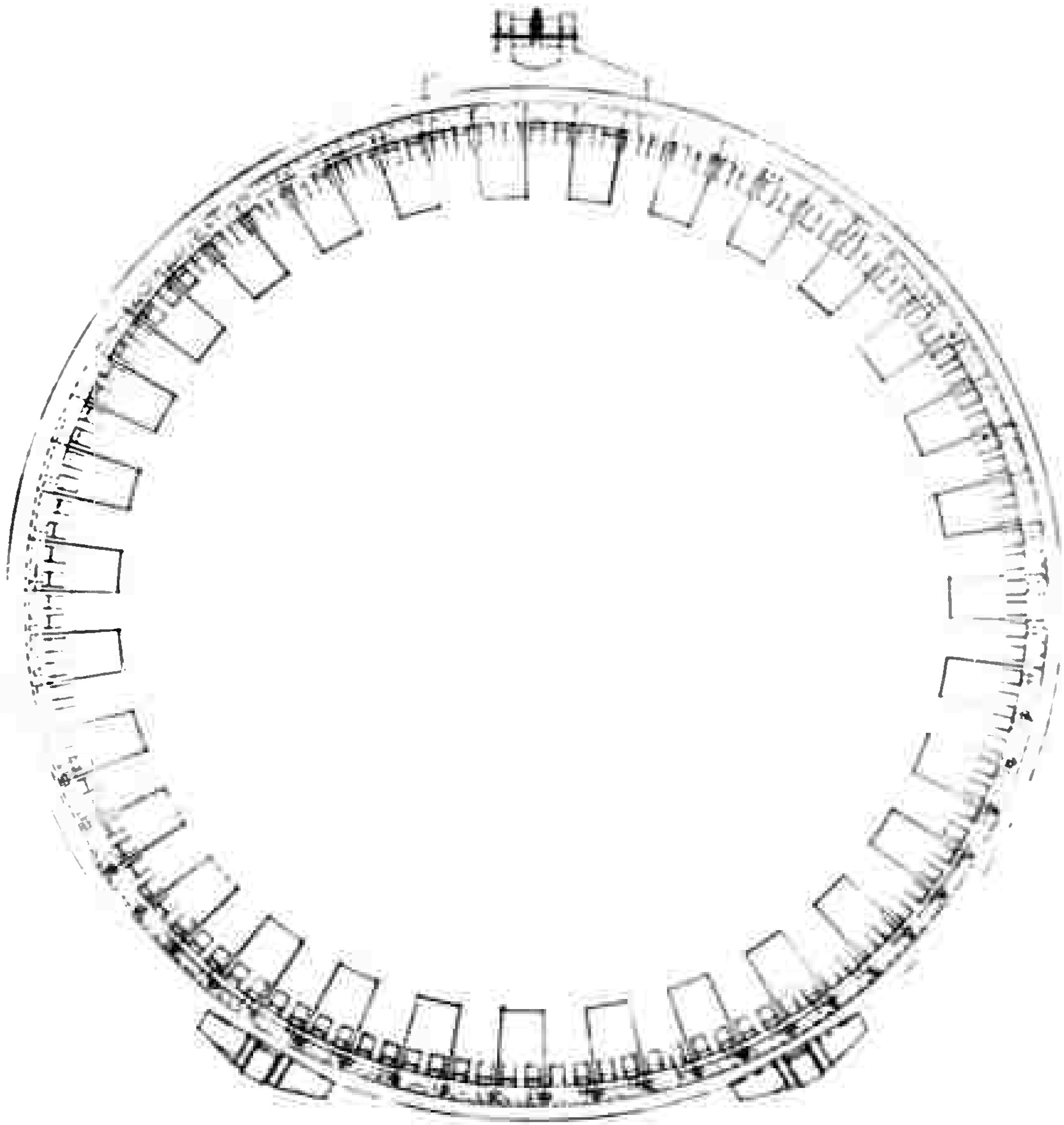


Figure 4. Axial view of the interior structure.

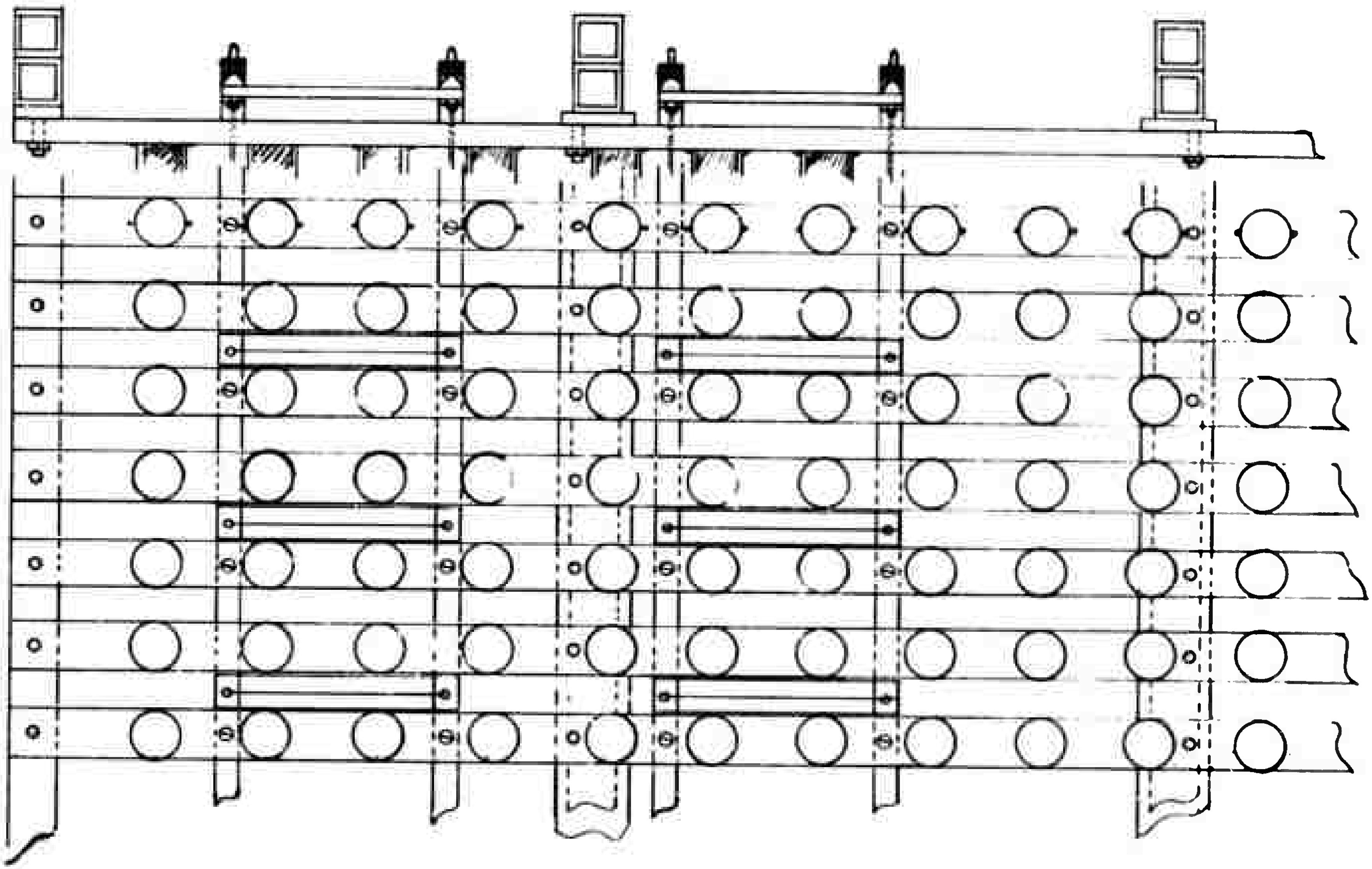


Figure 5. A segment of three rings as seen from an interior point on the axis of the rings. A cross-sectional view is shown at the top.

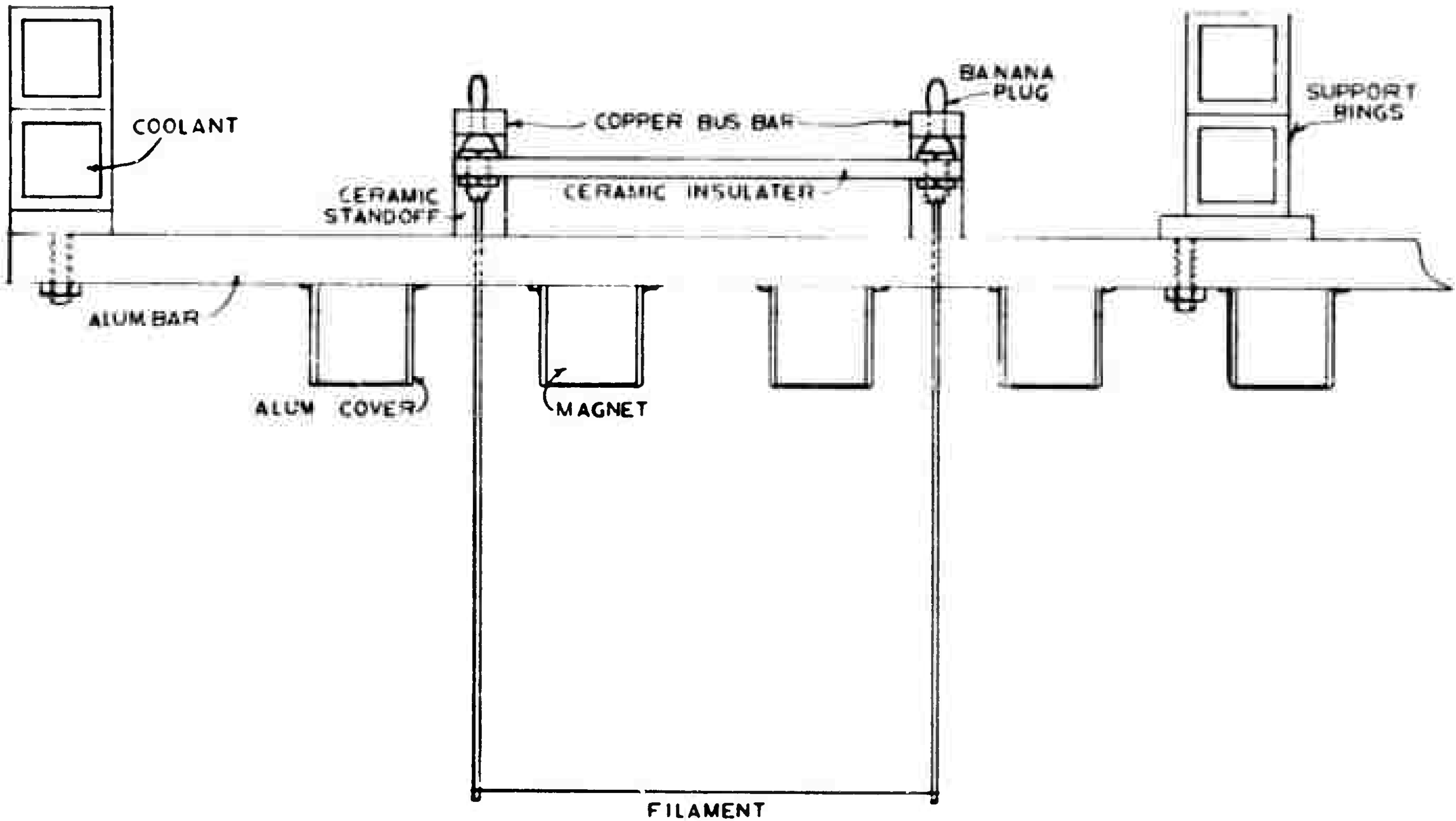



Figure 6. A cross-section of a three-ring segment.

Figure 7. Support Frame for Magnet Cage.

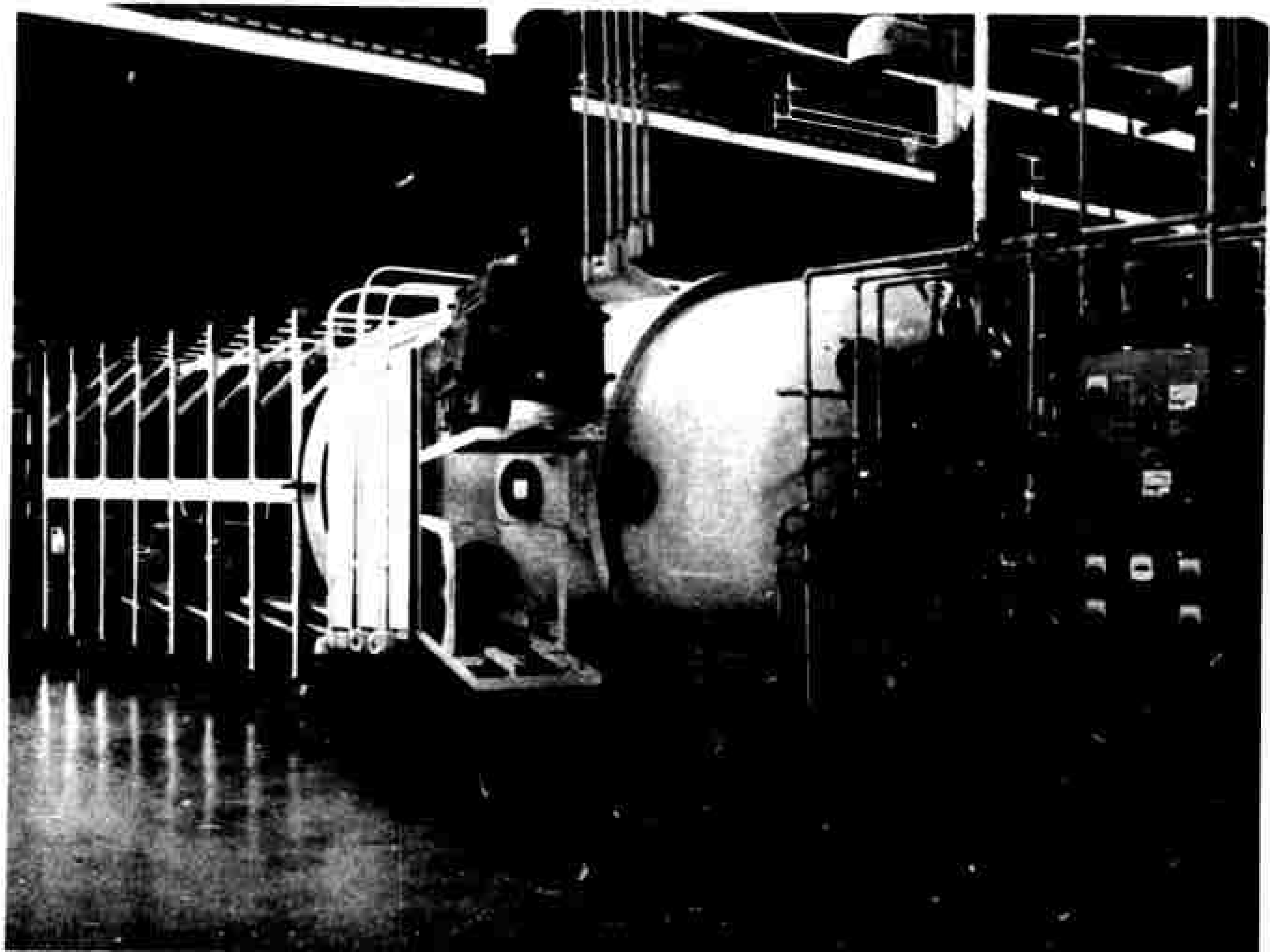


Figure 8. Support Frame for Magnet Cage

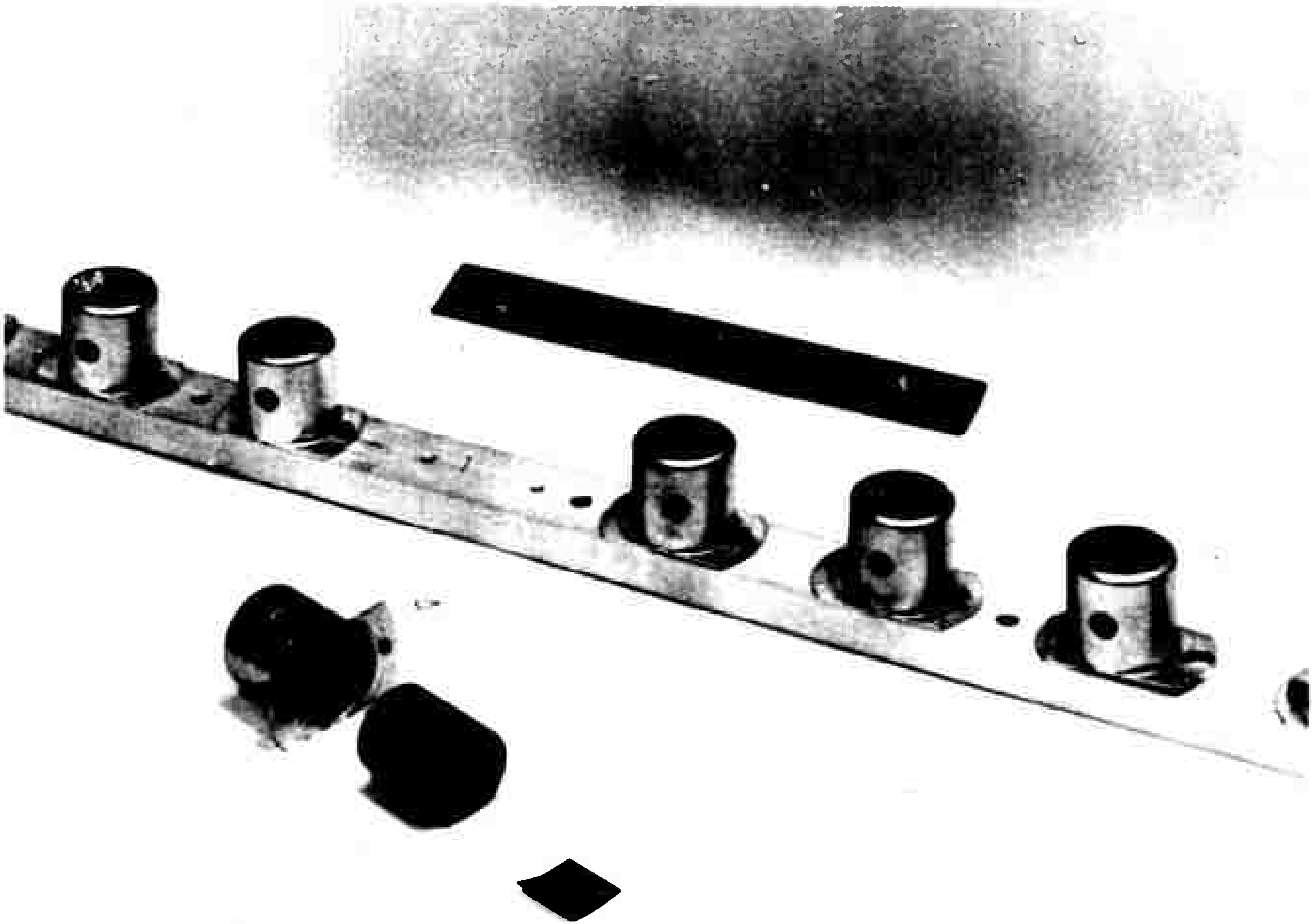


Figure 9. Magnets Mounted on Support Bars. Exploded View Shows Aluminum Can, Mag : and Spring Spacer.

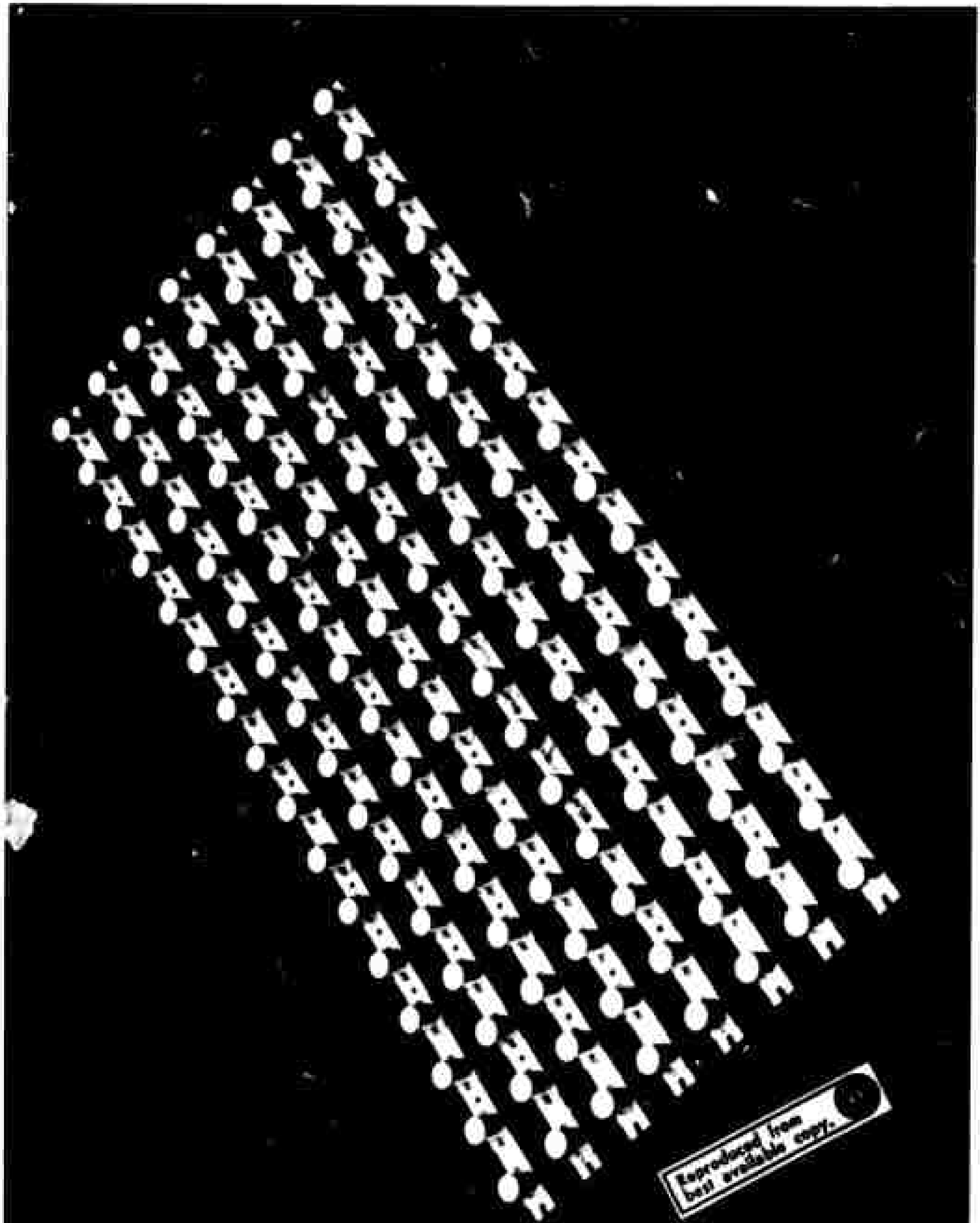



Figure 10. Typical Array of Magnets Covering the Inside Walls of the

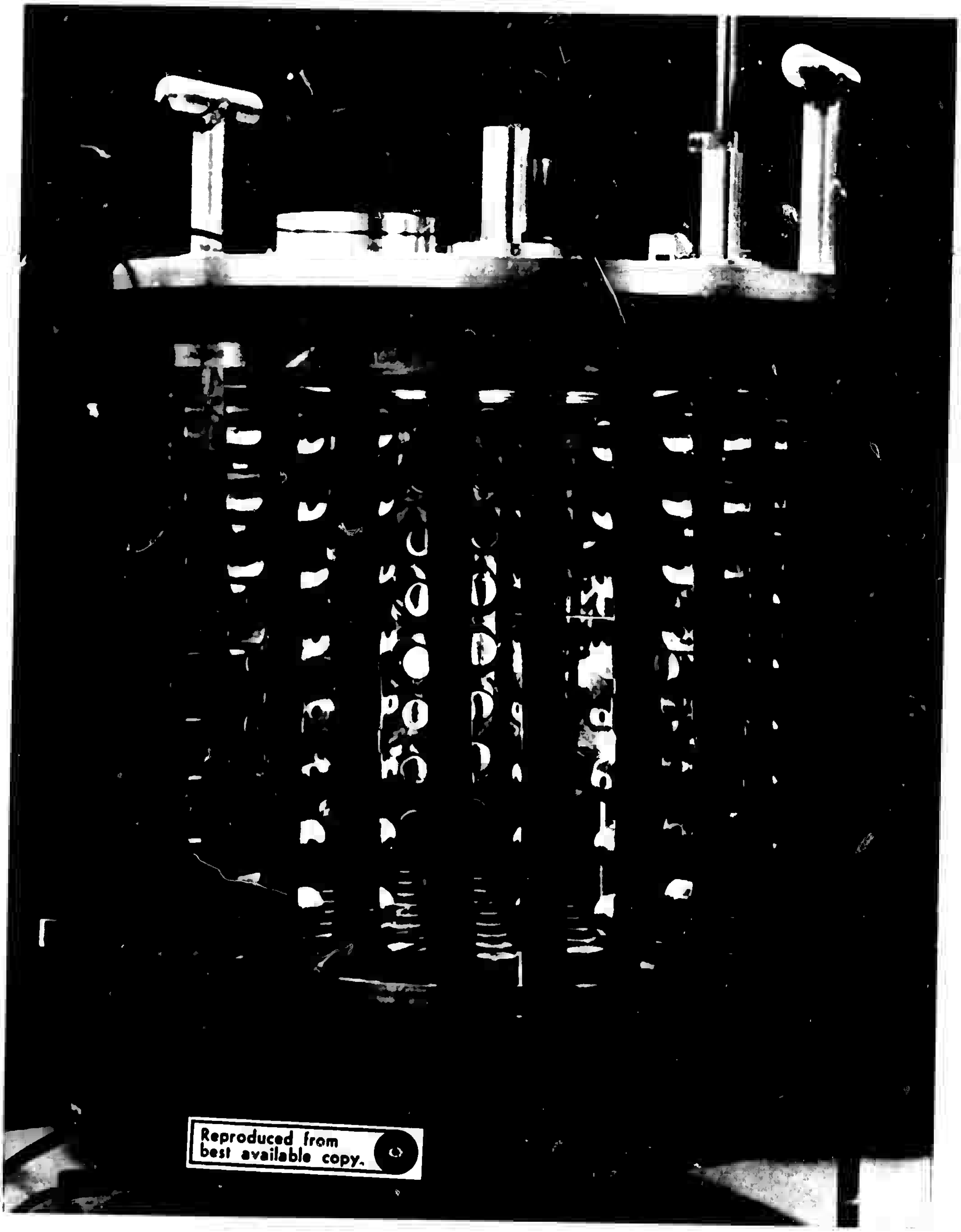



Figure 11. Test Plasma Facility with Argon Plasma at $n_e = 10^{11} cm^{-3}$.


Figure 12. Erosion Pattern on Magnets due to Electron Bombardment.

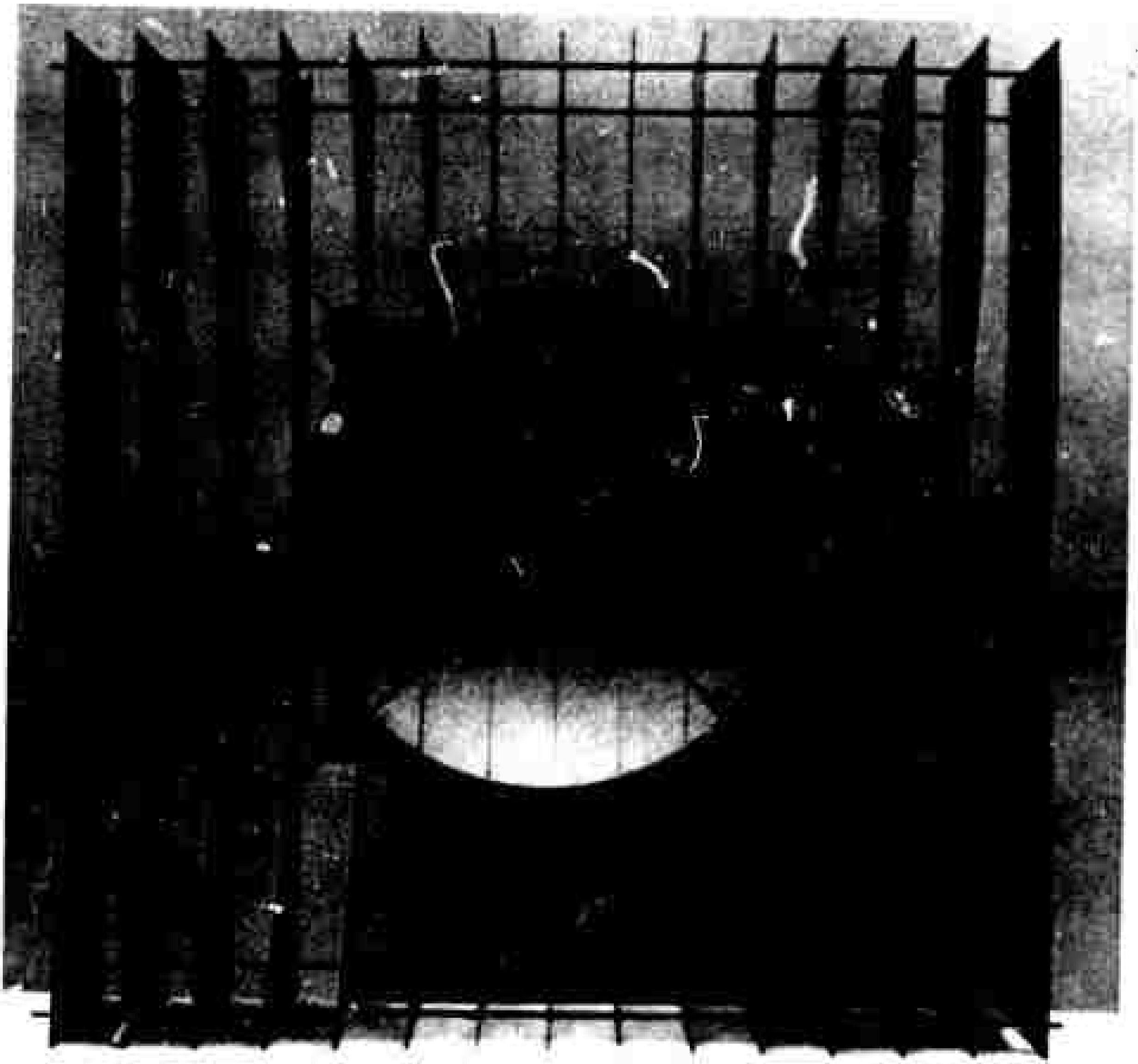


Figure 13. One meter diameter, 10 cm wavelength microwave dish antenna and lens.

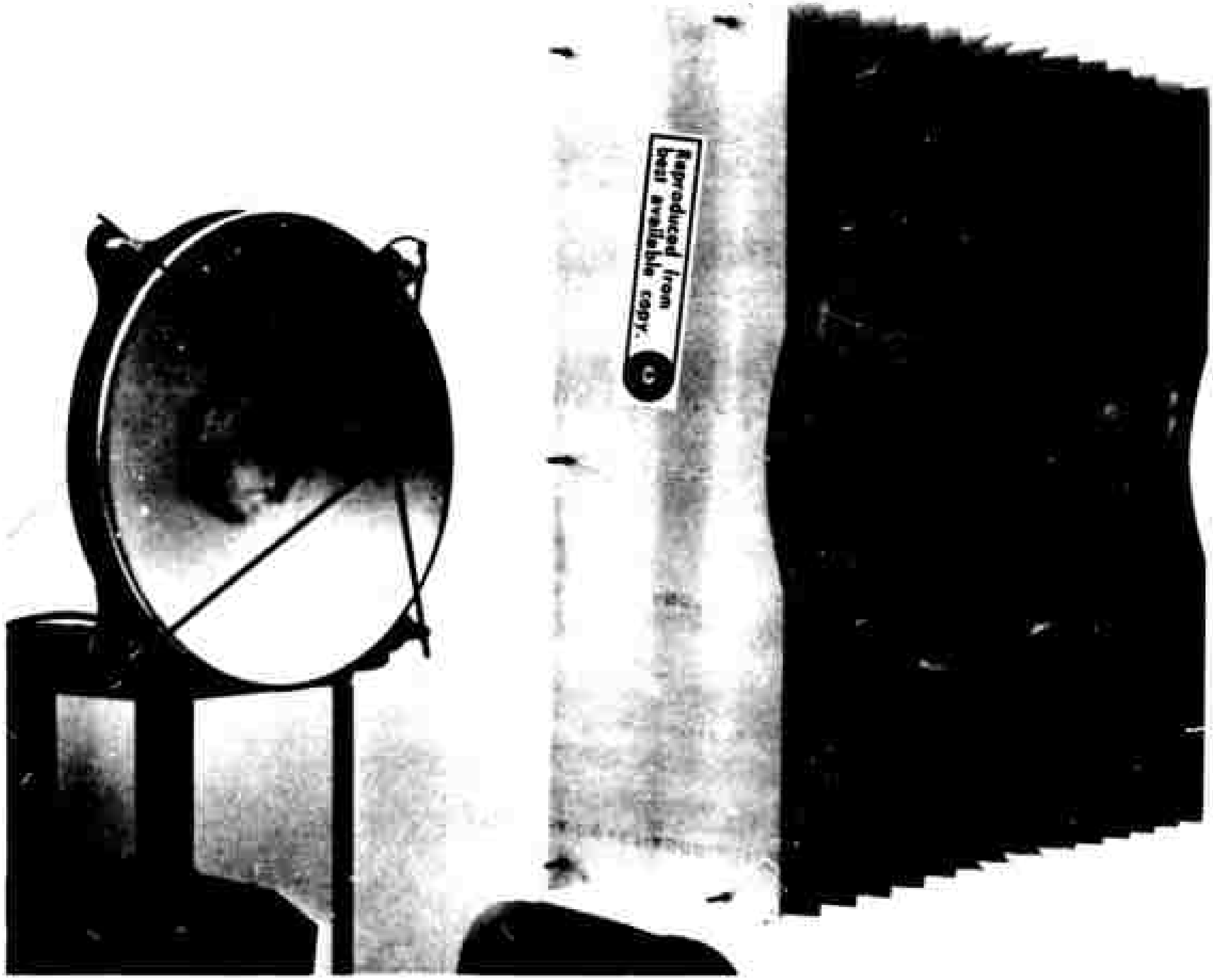



Figure 14. One meter diameter, 10 cm wavelength microwave dish antenna and lens.